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Operational Concepts for Uninhabited Tactical Aircraft

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1. ABSTRACT

This paper describes experiences with five remotely piloted flight research vehicle projects in the developmental flight test phase. These projects include the Pathfinder, Perseus B, Altus, and X-36 aircraft and the Highly Maneuverable Aircraft Technology (HiMAT). Each of these flight projects was flown at the NASA Dryden Flight Research Center. With the exception of the HiMAT, these projects are a part of the Flight Research Base Research and Technology (R&T) Program of the NASA Aeronautics and Space Transportation Technology Enterprise. Particularly with respect to operational interfaces between the ground-based pilot or operator, this paper draws from those experiences, then provides some rationale for extending the lessons learned during developmental flight research to the possible situations involved in the developmental flights proceeding deployed uninhabited tactical aircraft (UTA) operations. Two types of UTA control approaches are considered: autonomous and remotely piloted. In each of these cases, some level of human operator or pilot control blending is recommended. Additionally, "best practices" acquired over years of piloted aircraft experience are drawn from and presented as they apply to operational UTA.

2. INTRODUCTION

This paper describes experiences with five NASA-sponsored uninhabited flight research vehicle projects in the developmental flight test phase. The intent is to draw some insights from this set of experiences that might apply to operational concepts for uninhabited tactical aircraft (UTA). Lessons learned from these experiences may have more applicability to the developmental flight test phase of operational vehicles, but such application requires special attention as new air combat tactics involving UTA emerge. Following the descriptions and characterization of the five projects, some suggestions are made for future operational systems, and a set of "best practices" is offered.

3. GENERIC CATEGORIZATION OF REMOTELY-PILOTED VEHICLES

As a start, an attempt is made to set out useful generic categorizations that span the five flight projects. The first categorization is more of a reminder that the project experiences come from the developmental testing phase. Having development testing and operational deployment experiences would have been good, but only development testing was within scope of these flight research projects.

One important variation between projects pertains to the amount and type of human interaction involved in controlling the aircraft. High bandwidth of interaction up to rigid-body frequencies is characterized as "remotely piloted." Low bandwidth of control, to the point of infrequent human interactions, tends toward "autonomous." Note that reaching 100-percent autonomy was not an objective of these five projects.

Other generic categories involve the amount of system redundancy and the action taken to constrain public exposure in the event of catastrophic failure. All five vehicles are recovered through conventional horizontal landing. The launch methods are either horizontal takeoff or air launched. A characteristic of any of these developmental testing projects is that the vehicles must stay within the test range. For piloted aircraft, the requirement to stay within the test range can be met almost by assumption. For an uninhabited vehicle, however, assurance of positive control with respect to the test range boundaries, even after major system failures, becomes a dominant requirement. Thus, one of the key descriptors in characterizing the various flight vehicles is by their approach to either backup recovery or flight termination. Related is their approach to systems redundancy.

4. DEVELOPMENT TESTING EXPERIENCE

Figure 1 lists the projects in order of increasing airspeed. The Pathfinder, Perseus B, Altus, and X-36 vehicles are part of the NASA Flight Research Base Research and Technology (R&T) Program. These vehicles are currently flying or have been flown at Dryden Flight Research Center, Edwards, California.

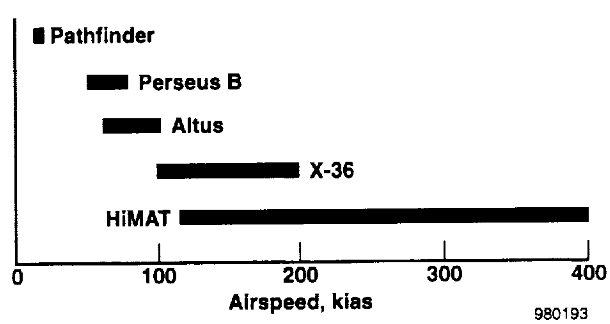

Figure 1. Vehicle projects in order of increasing airspeed.

The first three are members of the Environmental Research Aircraft and Sensor Technology (ERAST) set of projects. Pathfinder is a solar-powered very high-flying airplane. The Perseus B and Altus are high-altitude, slow-flying, consumable fuel aircraft. These aircraft are designed for uninhabited aircraft operational applications. The X-36 and HiMAT (Highly Maneuverable Aircraft Technology) differ because they are subscale, remotely piloted vehicles which are representative of hypothetical, full-scaled, inhabited vehicles. These subscale vehicle designs are probably different than they would have been if there were no intent to have them up-scaleable to piloted versions. With one exception these five vehicles are currently being flown. The last flight of the HiMAT occurred nearly 2 decades ago; therefore, those flights used technology that is antiquated by today's standards. However, important lessons involving vehicles with supersonic capabilities were learned. Remembering such lessons would prove helpful at this point. The HiMAT test results and a program assessment overview are provided in reference 1.

4.1 Pathfinder

The solar-powered Pathfinder was designed, built, and operated by AeroVironment, Incorporated, Monrovia, California. It takes off horizontally and flies at very low airspeed (16.6 kias) throughout its mission. Pathfinder has a wingspan of 100 ft, has wing chord of 8 ft, and weighs 570 lb. The flight control systems have triplex redundancy for the sensors and duplex computers. Emergency positive recovery is by way of a off-center drag chute which initiates a helical decent. This flight program is in the developmental flight test phase. Operator interface is by way of a joystick through an automatic pilot.

Figure 2 shows the Pathfinder. Flights under NASA sponsorship occurred from 1995 to 1997. The most notable accomplishment is the setting of the World Altitude Record for propeller-driven aircraft of 71,500 ft on July 7,1997. Further information is available in reference 2.

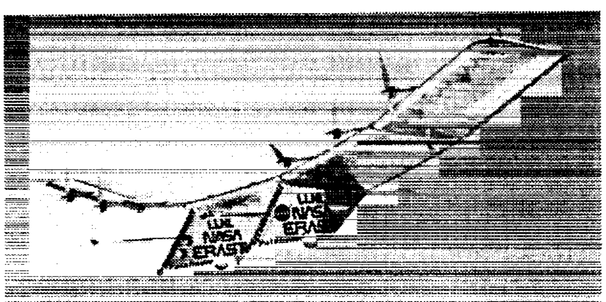

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Figure 2. Pathfinder solar-powered aircraft.

4.2 Perseus B

The Perseus B was designed, built, and operated by Aurora Flight Sciences Corporation, Manassas, Virginia (figure 3). This pusher-prop, high-altitude, remotely piloted aircraft takes off and lands horizontally. The Perseus B is 26.2 ft long, has a 58.6-ft wingspan, and weighs 2700 lb. Its maximum airspeed is 80 knots, and the flight control system is simplex. Emergency positive recovery makes use of a termination chute.

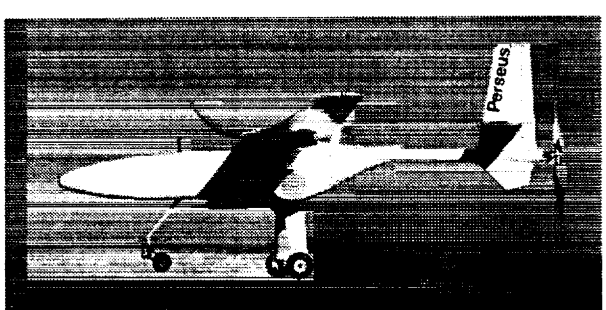

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Figure 3. Perseus B in flight.

Flight activity was from 1994 to 1996, with a premature ending to the flight series because of a mishap. Lessons learned from that mishap are presented in reference 3. Completion of the envelope expansion is planned for 1998.

4.3 Altus

The Altus was designed, built, and operated by General Atomics Aeronautical Systems, Incorporated, San Diego, California (figure 4). The Altus I is based on Predator and uses a single turbocharger; whereas, the Altus II uses a dual turbocharger. The Altus is 21.8 ft long, has a 56.3-ft wingspan, and weighs 1632 lb. Its maximum airspeed is 100 knots, and systems redundancy is duplex. Backup recovery is through a Global Positioning System (GPS) way-point loiter. A termination chute deploys if the way-point loiter does not work. Operator interface is through a head-up display (HUD), with forward-looking camera. Control inputs are through stick and rudder pedals.

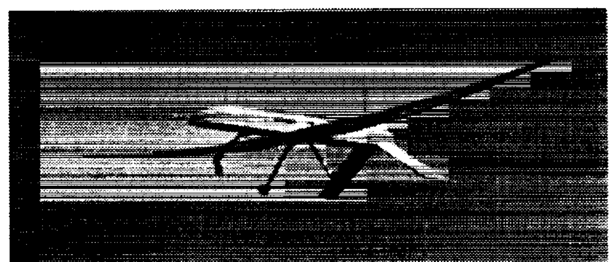

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Figure 4. Altus in flight.

Flight testing began in 1996 and continued into 1998. Achieving a maximum altitude of 65,000 ft is planned for later in 1998.

4.4 X-36 Aircraft

Figure 5 shows the X-36 aircraft. This remotely piloted vehicle was designed, built, and operated by the Boeing Phantom Works, St. Louis, Missouri. This airplane is powered by a Williams Research F112 turbojet. The NASA Ames Research Center, Mountain View, California, provided management and strong technical contributions, and NASA Dryden provided flight facilities and operational support.

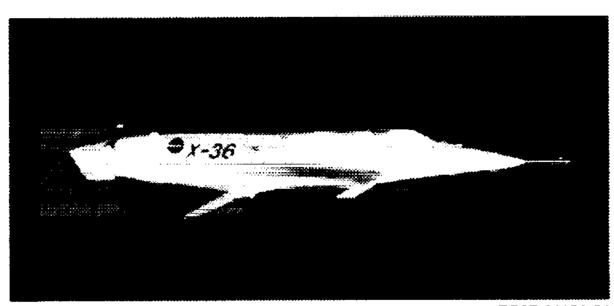

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Figure 5. X-36 in flight.

The X-36 is 18 ft long, has a 10-ft wingspan, and weighs 1270 lb. This vehicle takes off and lands horizontally, has flown to a airspeed of 200 knots, has a simplex flight control system, and is equipped with a parachute emergency recovery system. Pilot interface consists of proportional commands to the flight control system through stick and rudder pedals. A very advanced HUD is used with additional features to make piloting from a ground-based cockpit an effective control mechanism.

This aircraft is in the developmental flight test phase. Flights began in the spring of 1997 and ended before the end of that year. Thirty-one flights have occurred, and no significant problems were encountered. All program objectives were met or exceeded. Further information is available in references 2 and 4.

4.5 HiMAT

Figure 6 shows the HiMAT. This remotely piloted vehicle differs from the other aircraft described in this paper because it was air launched from a B-52 aircraft. However, it landed horizontally in a manner similar to the Pathfinder, Perseus B, Altus, and X-36 aircraft. This aircraft was designed, built, and operated by the North American Aviation Division of Rockwell, Incorporated, El Segundo, California. The flight control system used a ground-based computer interlinked with the aircraft through an uplink and downlink telemetry system. An onboard backup flight control system had duplex redundancy. The maximum airspeed attained was 400 knots. The HiMAT is 23.5 ft long, has a 15.6-ft wingspan, and weighs 3428 lb.

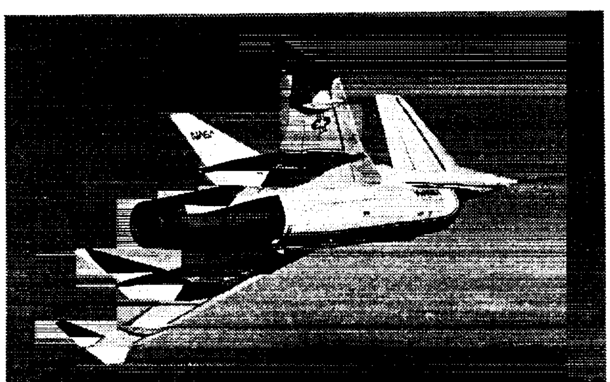

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Figure 6. HiMAT remotely piloted aircraft in flight.

From 1979 to 1982, 26 flights were accomplished. The HiMAT program was completed without any loss of vehicles.

The pilot's interface used proportional stick and rudder pedals for control, with inputs commanding the computer in the primary flight control system. Pilot displays were quite crude. Conventional instrument panel gauges were used and a forward-looking camera served as the source for a cathode-ray tube display. Neither a HUD nor an imbedded symbology on the cathode-ray tube display were used. Further information is available in references 1 and 5.

5. LESSONS LEARNED

Because experiences described here were gained with developmental aircraft, suggestions regarding future UTA systems are being limited to developmental aircraft. These suggestions are grouped into matters pertaining to control approach and matters affecting vehicle design tradeoffs.

5.1 Vehicle Control Approach

On one extreme, vehicle control approach can involve a human operator (pilot) tightly coupled into the control loop. At the other extreme, the vehicle can be completely separate from human interaction (autonomous control). For operationally deployed vehicle systems, the design might draw from the full range of possibilities in vehicle control approach. For developmental vehicle systems, some level of human interaction is recommended, even for the autonomous systems. Some considerations for this range of approaches are given in the Remotely Piloted Control and Autonomous Control subsections.

5.1.1 Remotely Piloted Control

Uninhabited vehicles controlled by remote pilots depend on the pilots being well informed on the complete situation pertaining to the vehicle and mission. In a ground-based remote cockpit, the primary sources of information for the operator or pilot are presented in visual displays or through audio means. The following subsections on visual cues and audio cues address these forms of information transfer.

Visual Cues

Cockpit design is critical, particularly with respect to visual displays. Situational awareness should be as complete as with an inhabited aircraft. This awareness should be maintained even with the absence of motion cues. As a result, extra care should be taken to supplement the standard displays with additional cues that can provide the missing information.

Audio Cues

Audio cues from an onboard microphone can provide important additional information. For the X-36 aircraft, such a cue was provided to the remote pilot. Cues allowed identification of some anomalous engine operations early in the X-36 project. This timely identification prevented difficulties which could have reasonably been expected to occur if corrective action not been taken.

5.1.2 Autonomous Control

Uninhabited vehicles designed for autonomous control should provide some means of oversite by a human operator and limited interaction. During developmental testing, an increased capability for human interaction is usually beneficial. Two desirable attributes of the system design include blending of human interaction and graceful assumption of control by the human.

Provide for Limited Human Blending

In nearly all cases, the ability to blend human control with automation should be provided. Even for systems intended for fully autonomous operational deployments, during the early stages of developmental tests, the human ability to react to unforeseen circumstances can only be used if this system allows for human input. A system designed with the possibility of human control blending must provide sufficient useful information displayed to the human such that timely monitoring and control can take place. This inclusion of the human yields a system design with improved robustness; therefore, the likelihood of such a system being successful in its developmental testing is greatly increased.

Ensure Graceful Assumption of Control

With human blending capabilities, the system should provide for graceful assumption of control by the human operator. Displays must be sufficient to provide dynamic information such that the human can begin to make control inputs without being out of phase with the vehicle response.

5.2 Vehicle Design Tradeoffs

At the time of vehicle design tradeoffs, assessments should be made relative to the full range of human operator involvement in vehicle control. Considerations should encompass (1) the degree to which large uncertainty in vehicle environment might be encountered and (2) the necessity to overfly populated areas.

5.2.1 Managing Uncertainty in Vehicle Environment

Uncertainty in vehicle environment can occur when the operational environment departs from the better controlled test environment. It also occurs when the mathematical models of the vehicle environment inadequately represent the actual flight environment.

Human interaction will typically be required when the degree of departure from prior experience at the vehicle configuration level becomes large. Thus, an unusual aerodynamic configuration is more likely to require human operator intervention during the test program than a more conventional aerodynamic configuration.

When the complexity of the mathematical models and systems is necessarily great, there is more likely an increased sensitivity to vehicle component interactions. If some interactions remain unmodeled, the undesirable impact on the vehicle response is usually increased. Thus, the possibility that a human operator must intervene significantly increases.

When the individual technologies are mature, then the integrated set packaged as a vehicle system will probably yield well-behaved characteristics. The corollary to this situation is when some included technologies lack maturity, a greatly increased need for human operator override capabilities in order to have a robust system in the face of environmental uncertainties results.

5.2.2 Testing Beyond Restricted Range

When testing extends outside of protected range, the public exposure to mishaps must be considered. Human operator capability may play an important role in minimizing public exposure.

6. BEST PRACTICES

In many ways, best practices in vehicle design which were developed over many years of piloted aircraft design also apply to uninhabited aircraft design. Attention should be given the overall design approach (make it balanced) and to the potential role of the human operator or pilot. These two topics are addressed in the Balanced Design Approach and Real-Time Choices subsections.

6.1 Balanced Design Approach

A balanced approach should be taken beginning with vehicle and system design, regardless of vehicle control approach selected. This approach should apply to all categories of specialists, including pilots and flight operations personnel. Inclusion of experienced individuals is particularly important during the design phase of autonomous vehicles. Care should also be taken to include all steps in vehicle checkout, especially the inclusion of a full set of validation tests.

6.2 Real-Time Choices

A pilot or operator can provide high-quality, high-integrity, real-time choices (i.e., decide whether or not to intervene) on matters which may be overlooked or are difficult to foresee during the design phase. This decision making can only be translated into value to the program if the design incorporates sufficient capabilities for the pilot or operator to assess system performance. A blended input for corrective action by the pilot or operator should also be incorporated.

Such capabilities should be favored when uncertainties in vehicle modeling are high. As a note of caution, the benefits that can be accrued by such features are likely to be understated or missed in cost-benefit tradeoffs because of the difficulties in translating off-nominal or unmodeled situations into numbers.

7. CONCLUDING REMARKS

The majority of the flight experience in uninhabited vehicles obtained at NASA Dryden Flight Research Center has involved low-speed developmental vehicles. The exception, the Highly Maneuverable Aircraft Technology, occurred 2 decades ago when many of the technologies that are now taken for granted were still promises for some time in the future.

The extension of lessons learned from those flight experiences to the high speeds and operational deployments anticipated in future uninhabited tactical aircraft should be done cautiously. Furthermore, extending lessons learned from developmental testing (as these all were) to operational deployments is an additional major step in application. These extensions should also be done with care.

Finally, the adoption of best practices acquired over years of piloted aircraft experience should be an important part of the design process followed by all uninhabited tactical aircraft design teams.

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13. ABSTRACT (Maximum 200 words)

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14. SUBJECT TERMS
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